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SUBJECT: The Contribution of Apollo Combustion Effort to Flammability Prediction Technique - Case 320

DATE: December 11, 1967

FROM: S. S. Fineblum

ABSTRACT

The author presented a briefing on flammability prediction techniques to the Apollo Program Office on December 5, and on December 7 it was given again by T. L. Powers to Dr. Seamans.

The requirements for flammability prediction were felt to be theoretical and design theories, a body of empirical knowledge, and reliable, efficient means of design verification. The Apollo Program combustion investigations, although specifically directed toward suppressing flame spread in the Apollo spacecraft cabin, have produced results which promise to be more generally applicable. The full-scale tests to verify the use of materials and arrangements used in the Apollo will have application to a large class of future, technically advanced, vehicles. A large amount of flammability data generated for nonmetallic materials in oxygen was assembled and widely distributed in the form of a computerized listing, denoted COMAT. In general, the standardization of test techniques and the test results from Apollo Program efforts are immediately useful and will contribute to the theory and technology of flammability prediction.

The briefing was generated in response to the following action item on flammability predictive techniques from Dr. Seamans October 13 review:

> "Continue to examine the development of predictive capabilities and techniques in the area of fire hazards and flammability assessment for manned systems. The empirical results of current tests should be used not only to validate LM and CSM safety, but also to generalize the theory and validate the mechanism of fire and flame propagation which may extend the capability of these data or techniques to future manned systems, including aircraft, submersibles, space systems, etc."

At the conclusion of the December 7 briefing, Dr. Seamans requested that a summary of the applicability of the Apollo flammability work to future manned systems, with emphasis on interagency coordination, be prepared for possible inclusion with the NASA budget supplementary materials in January.

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MEMORANDUM FOR FILE

The writer presented a briefing to the Apollo Program Office December 5 morning meeting on the contribution of the Apollo combustion investigations to flammability prediction techniques for future vehicles. This subject matter was later presented to Dr. Seamans by T. L. Powers on December 7.

In order to make reliable predictions on the flammability of future vehicle designs we need:

a. a general theory of how things burn, especially diffusion flames;

b. a design theory to relate the general knowledge to practical decisions;

c. a data bank for specific numerical support of expectations and decisions; and

d. reliable, efficient test techniques (first vu-graph).

Apollo combustion investigations have produced four significant accomplishments. Full-scale cabin tests have been performed. A large amount of nonmetallic combustion data has been produced. The program has developed and documented test techniques and made some beginning contributions to a combustion theory (second vu-graph).

The full-scale spacecraft tests had as their purpose the urgent necessity of establishing the combustion safety prior to manning of specific spacecraft and they had to be performed with a minimum of delay and within the limits of available manpower and facilities. Dominated by the necessity to directly support the Apollo Program, the tests were performed under specific, somewhat limited, conditions (third vu-graph).

During these full-scale tests a large quantity of data on the ignition and propagation characteristics was generated for practical materials, shapes, and assemblies. Test techniques for full-scale testing are being refined and improved. In addition, the tests confirmed LM cabin combustion resistance and the general basis for recent design decisions (fourth vu-graph).

A central effort of the program has been the accumulation of combustion data on nonmetallic materials. As a result of this effort there is now in COMAT ("Characteristics of Materials Test Data Listing") the largest collection of data (about 2,800 entries) on the ignition, flame spread, and some pyrolysis characteristics of practical materials. This collection totals more than all other previous oxygen combustion data.

The effects of acceleration fields on combustion of some select materials have been studied in 1 to 15 g tests at White Sands Testing Facility and elsewhere, as well as during limited zero-g tests, which were reported by Kimzey and his associates.* This newly generated data has been widely distributed and will become generally available (fifth vu-graph).

Another result of program efforts will be a handbook, "Nonmetallic Materials for Spacecraft," which is being published under the direction of the Reliability and Quality Assurance Directorate at MSC. This handbook will summarize the findings of the program and the latest technical literature in a form for the greatest general usefulness. It will be complete next September (sixth vu-graph).

The extensive test work stimulated the development and standardization of test techniques, (see "Procedures and Requirements for the Evaluation of Spacecraft Nonmetallic Materials," MSC-A-66-3). The sample test methods have been revised by joint effort of the people doing the actual testing. For example, the problems of measuring flame speed during acceleration tests have encouraged improvement on the instrumentation and operation of such tests. Full-scale combustion experience has contributed to techniques which will be applicable to other vehicle systems because the size and the shape and the materials and the general configuration are going to be at least similar. During a recent Combustion Institute conference** it was the unanimous concensus that full-scale techniques are, at present, the best way of getting dependable, practical, combustion information (seventh vu-graph).

The program effort includes an attempt to integrate present knowledge into a general combustion theory. The work at Atlantic Research has produced progress, both by experiment and analysis, toward understanding what influences flame spread and

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*NASA Technical Report, NASA TR R-246, prepared by Manned Spacecraft Center

**First Meeting of Eastern Section of the Combustion Institute at Mellon Institute, Pittsburgh, November 27-28, 1967 flame height and the effect of acceleration on combustion. History has shown that whenever a large body of logically ordered knowledge has been accumulated the result has been a stimulus to the theoreticians to explain and to integrate this newly acquired experimental knowledge. There is every reason to believe that this new accumulation of data points will similarly stimulate the advance of combustion theory (eighth vu-graph).

There remains, however, a distinct need for additional effort and the limitations of the program's contributions to flammability prediction techniques are quite obvious. First, the nonmetallic materials tested were primarily limited to Apollo materials. Only a pure oxygen atmosphere, and only nominal pressures (5.0, 6.2 and 16.5 psi) were used during the tests. Very little high-g data and less zero-g data were generated. Toxicity and pyrolysis measurements have been handicapped by relatively insensitive sensing techniques. The overall and gross deficiency of the available combustion theory, characteristic of not only this program but of available technology generally, has not yet been appreciably repaired by the limited efforts in this direction (ninth vu-graph).

S. S. Fineblum

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Attachments
Vu-graphs

GENERAL REQUIREMENTS
FOR FLAMMABILITY PREDICTIVE TECHNIQUES

- GENERAL THEORY OF COMBUSTION
- DESIGN THEORY
- DATA BANK
- DESIGN VERIFICATION

[illegible]

- [illegible] CONFIGURATION
- [illegible] COMBUSTION DATA
- TEST TECHNIQUES
- COMBUSTION THEORY

[illegible] CONFIGURATION

NEED FOR:

- TO ESTABLISH COMBUSTION SAFETY PRIOR TO MANNING OF SPACECRAFT
- MINIMUM DELAY
- AVAILABLE FACILITIES AND MANPOWER

CHARACTERISTICS OF TESTS:

- FULL SCALE TESTS OF SPECIFIC LM AND CM CABINS
- 100% OXYGEN
- NOMINAL OPERATING PRESSURES
- 1G ACCELERATION

[illegible] SYSTEM CONFIRMATION

RESULTS:

- DATA ON IGNITION AND PROPAGATION CHARACTERISTICS
  - IGNITION POWER, TEMPERATURE, TIME
  - PROPAGATION MEASUREMENTS - MOVIES
- REFINEMENT OF TEST TECHNIQUES
- CONFIRMATION OF LTA-8 CABIN
  - NO SIGNIFICANT PROPAGATION
  - NO MATERIALS COMBINATION SURPRISES
- INDICATION OF SUCCESS OF DESIGN APPROACH

NONMETALLIC MATERIALS COMBUSTION DATA

- LARGEST COLLECTION OF DATA ON PRACTICAL MATERIALS (COMAT)
  - 2800 ENTRIES
  - 1500 MATERIALS AND COMPONENTS

  IGNITION, FLAME SPREAD AND OUTGASSING IN 100% O_2 AT 16.5 & 6.2 OR 5.0 PSI
- EFFECTS OF ACCELERATION ON SELECT MATERIALS
- DISTRIBUTION OF TEST DATA
  - NASA CENTERS
  - NASA CONTRACTORS
  - USAF
  - FAA

"DESIGN HANDBOOK - NONMETALLIC MATERIALS FOR SPACECRAFT"
(SEPTEMBER 1968)

1 - CRITERIA

2 - COMBUSTION CHARACTERISTICS

3 - TOXICITY

4 - DESIGN CONSIDERATION

5 - COMAT

TEST TECHNIQUES

- STANDARDIZED MATERIALS SAMPLE TESTS (MSC-A-66-3-D)
- ACCELERATION TESTS
- FULL SCALE EXPERIENCE
  - APPLICABLE TO OTHER SYSTEMS
  - EXPERT CONSENSUS ON NECESSITY

COMBUSTION THEORY

- ATLANTIC RESEARCH STUDY
  - FLAME SPREAD
  - FLAME HEIGHT
  - ACCELERATION EFFECTS
- ANTICIPATE FURTHER ADVANCES AS RESULT OF ORGANIZED COMBUSTION DATA

PROGRAM LIMITATIONS

LIMITED MATERIALS TESTING

- APOLLO NONMETALLIC MATERIALS
- OXYGEN ATMOSPHERE
- RESTRICTED PRESSURES
- LITTLE HIGH-G DATA
- LESS ZERO-G DATA
- LIMITED TOXICITY MEASUREMENTS

DEFICIENCY OF GENERAL THEORY

BELLCOMM, INC.

Subject: The Contribution of Apollo Combustion Effort to Flammability Prediction Technique

From: S. S. Fineblum

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